Analysis Tool for Monte Carlo Data

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Johnson Space Center (JSC) has developed an analysis tool that engineers can use to quickly gain a better understanding of a spacecraft design solely through analysis of Monte Carlo simulation data sets, thus reducing the time required within each design and analysis cycle (figure 1). This cycle iterates during the project life, in effect multiplying the improved efficiency this tool provides.

Monte Carlo simulations, used extensively during the design and analysis cycle of spacecraft development projects, consider a wide range of design parameters to generate thousands of flight scenarios that must be analyzed in detail by flight dynamics engineers.

These simulations create results that represent test data without the high costs associated with conducting real ground and flight testing. Historically, the analysis of these types of data for a fully integrated spacecraft is mostly performed manually on a case-by-case basis, often requiring several analysts to write additional scripts to sort through large data sets to identify the driving design variables. This process alone can take months.

But now, engineers have a consistent analysis methodology by which they can study a given data set in detail and gain insight into a design, regardless of whether they created it or someone else created it. This tool provides structure to the analysis process and helps engineers focus on problem areas within the current design.

The tool uses two tractable pattern recognition algorithms to search through large data sets to identify variables and variable subsets that influence a specific performance metric. The analyst classifies each simulation run in a Monte Carlo set as either a successful run or a failed run. With this information, algorithms within the tool create mathematical models of the data in both the successful-run class and the failed-run class. Subsequently, the two data classes are compared, and the differences between each are used to then identify and rank the design parameters according to their influence on a specified performance metric.

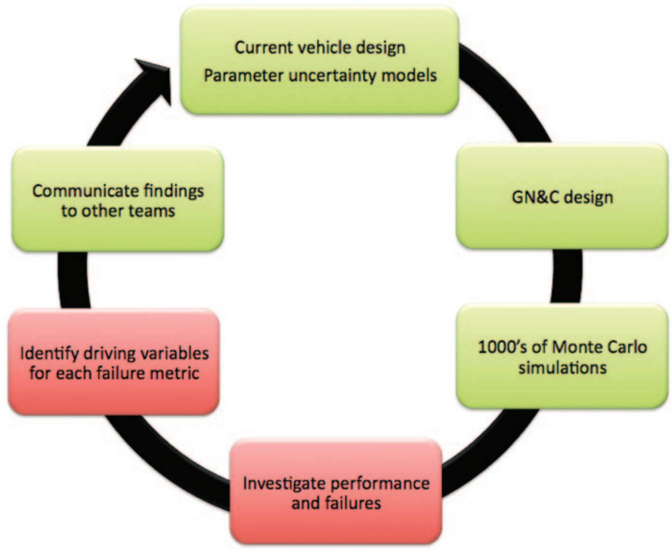

Fig. 1. *Spacecraft design and analysis cycle.*

This tool is readily applicable to a wide range of problems. It accepts the Monte Carlo data and the correlating performance metric information in a straightforward manner, so the user does not have to write problem-specific scripts. The method is 100% non-intrusive to the model equations and the simulation, and does not require running multiple Monte Carlo sets.

The only input requirement is that the Monte Carlo set must contain both successful and failed simulation runs. The inputs to the tool are three simple sets of data: the dispersed input parameters; the Monte Carlo simulation outputs, which can be saved at several discrete points in time along a trajectory; and the performance metrics information for each simulation run. The outputs of the tool are a list of ranked design variables and a list of ranked variable subspaces.

The two ranked lists provide different sets of information to an analyst (figure 2). Ranked design variables identify and prioritize which design changes should be addressed in subsequent design cycles; ranked variable combinations

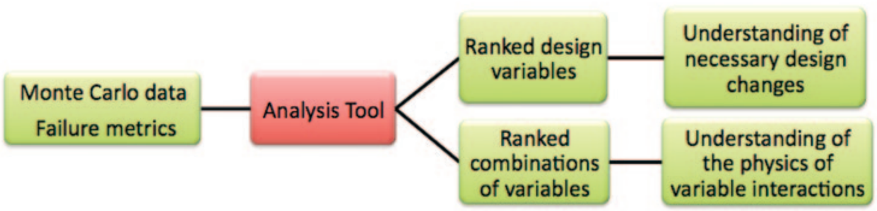

Fig. 2. *Analysis tool inputs and outputs.*

provide insight into the physics of the problem that is causing certain simulation runs to fail the specified performance metric.

The tool output does not analyze the data for the engineer, but it guides the engineer along the analysis process. In other words, it does not replace the analysts, but it does improve efficiency by identifying variables that the analysts must review in further detail.

Several of the tool's features make it readily applicable to most flight dynamics data analysis problems. One of the main benefits is the simple input data format required since most data sets can be formatted in this way. Additionally, the algorithms do not manipulate the data at any time throughout the analysis, nor do they require the analyst to do so. This means that each variable preserves its original units, and thus physical meaning. The method makes no assumptions on the uncertainty models of simulation input variables so it analyzes the dispersed inputs as they come.

Due to the tool's ease of use, an engineer who is not necessarily an expert in the fields of statistics or pattern recognition can still work with the algorithms, and understand and track how the tool analyzes the data. Of course, the engineer must possess basic problem domain knowledge to interpret the results the tool produces. Conversely, the tool is flexible enough that a system expert can introduce additional variables and modify performance metrics to drive the tool to converge on the design's most problematic issues.

The tool has recently been used to aid in the analysis of Monte Carlo data for the Orion vehicle to identify individual design variables that affect certain types of system failures. Due to the high computational cost of searching for failure regions in a problem with hundreds of variables, future versions of the analysis tool will be programmed on a graphical processing unit. In this way, engineers can explore—in detail—data sets containing hundreds of variables and thousands of variable combinations.